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THE EFFECT OF FACTORS RELATED TO THE CONQUEST OF SPACE

P. V. Vasil'yev and A. R. Kotovskaya

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16. Abstract

A review of the available literature and some original findings on the effect of two forms of accelerations on human and animal organisms. The accelerations dealt with the transverse and longitudinal accelerations. The most poorly tolerated type of acceleration with respect to man is the longitudinal form directed from head to seat. This form of acceleration causes acute redistribution of blood from the upper part of the body to the lower abdomen and the extremities, causing severe hypoxic disorders in the brain, disruption of vision and loss of consciousness. Various methods have been tried in order to reduce the adverse effects of acceleration on the human body. Such methods include g-suits, pharmacological preparations, immersion in liquids, form fitted chairs, and adjusting the angle of inclination of chair backs and head rests to meet the optimum with respect to the axis of the human body and the vector of the g-forces. Much promise is attached to these methods of increasing man's endurance to g-forces. The need for further research in this field is pointed out.

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THE EFFECT OF FACTORS RELATED TO THE CONQUEST OF SPACE

P. V. Vasil'yev[1] and A. R. Kotovskaya[2]

The Effect of the Long Term Action of Accelerations (G-Forces)

In recent years increased interest in the problem of the effect of /290* accelerations on the human organism has been due to the necessity of solving a number of pressing problems of providing flight safety on aircraft and particularly on spacecraft.

The leading dynamic factors of flight on modern aircraft include accelerations, whose physical effect can neither be avoided nor completely eliminated by the aid of any means, as can be done with respect to high and low temperatures, radiant energy, etc. Acceleration appears with a change in velocity or direction of movement of a body. The magnitude of acceleration, measured in m/sec^2 or in multiples of the velocity of an object falling freely to the Earth ($9.81\ m/sec^2$) is to a significant degree determined by the force acting on a body and by its mass and is designated by the letter G (from the Latin word gravitas - gravity). For example, an acceleration of $35\ m/sec^2$ can be approximately written as 3.5 G.

In medicine and biology four basic types of accelerations are differentiated: linear, radial, angular and Coriolis.

Linear acceleration appears with an increase or decrease in the velocity of movement without a change in its direction. The first case of change in velocity is frequently designated as a positive acceleration while the second as a negative acceleration. The combination of linear acceleration can be made according to the following formula:

$$a = \frac{V_t - V_0}{t},$$

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*Numbers in the margin indicate pagination in the foreign text.

where a is acceleration; V_t is terminal velocity; V_0 is the initial velocity; t is the time of change in velocity of movement.

Radial or centrifugal acceleration appears with a change in direction of the movement of the body. The most obvious example of this can be accelerations noted when making a loop in an aircraft, diving, and rotation on the centrifuge which is carried out for investigative training and expert goals, etc. According to calculations made by R. A. Stasevich and P. K. Isakov (1956), /291 acceleration during the dive of modern aircraft can attain 8 G or more.

The value of radial acceleration is determined according to the following formula:

$$a = R \cdot (\pi \cdot n)^2,$$

where a is acceleration; R is radius of rotation (in meters); π is the coefficient equal to 3.14; n is the number of revolutions per second.

Angular acceleration appears with nonuniform movement of the body about a circumference, i.e., with an increase or decrease in angular velocity; these are measured in radians per second. Angular accleration is the accumulation of two types of forces: one force tangentially directed toward the circumference of rotation (tangential acceleration) and one force directed toward the axis of rotation (normal acceleration).

Coriolis acceleration appears with a change in the radius of rotation and also in cases of approaching movement in one plane of movement in another plane. This type of acceleration is frequently encountered during flights aboard aircraft and spacecraft. The effect of angular Coriolis acceleration primarily causes reactions of the vestibular apparatus which are manifested in a polymorphous picture of sensory-vegetative disorders.

In this chapter only linear and radial accelerations are examined. Linear and radial accelerations, dependent upon their time of action, are arbitrarily divided into "shock accelerations" (up to tenths of a second) and "long term accelerations" (from 1 second or longer).

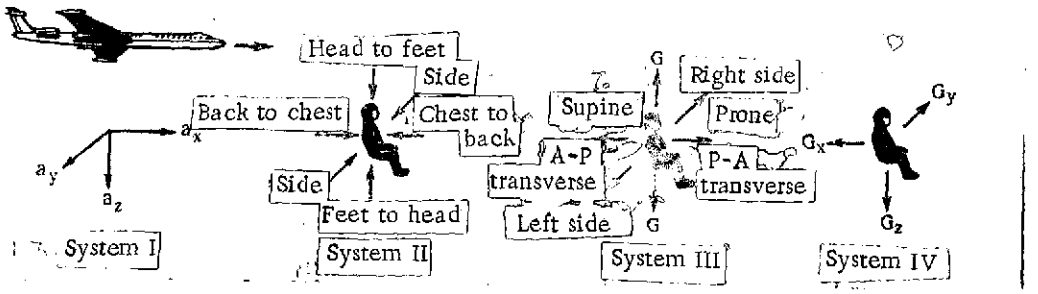
The direction of the force of inertia is always opposite the direction of acceleration. In medicine and biology the term "g-force" is frequently

employed. G-forces do not have dimensions and are expressed in relative units (unit), which indicate how many times the rate of a body has increased at a given acceleration in comparison with ordinary terrestrial gravitation. Dependent upon the direction of effective g-forces with respect to the vertical axis of the body, such g-forces are divided into longitudinal and transverse g-forces. With the direction of the vector of g-force from head to feet one speaks of positive g-forces, while with a direction from foot to heat -- of negative g-forces. Moreover, transverse (back to chest and chest to back) and lateral (side to side) g-forces are differentiated. The direction of the g-force vector has important consequences for the organism's reactions.

Unfortunately there is no uniform terminology in the classification of accelerations which has as its consequence frequently mistaken interpretations of the same facts and which causes difficulties in understanding materials when becoming acquainted with the literature. It seems to us that the table of equivalents of terminology accepted by representatives of a number of countries making up the Aerospace Commission on problems of accelerations deserves attention (Gell, 1961). In our section we shall cite only part of the data of this table which are directly relevant to the problems under examination (Table 27).

According to the recommendations of the Commission, the entire terminology is subdivided into two basic groups combined in graphs A and B (see Table 27). Graph A shows two variations of terminology pertaining to accelerations which are most frequently employed during investigations in the realm of astronautics, where the direction of acceleration of a mass is taken as the basis. In Graph B this role is played by the intertia of organs, tissues and liquids of the intact organism on an acceleration acting over the entire body. In the latter graph "local" expressions are shown which are used to describe the inertial reaction of the eyeball to the acceleration employed. Today, these are widely /292
distributed in the world of test pilots and design engineers. However, Table 27 does not contain a number of important factors in the effect of accelerations on the organism (time of action, gradient of increment, etc.), which requires further improvement of terminology and classification (G. L. Komendantov, 1966; B. M. Savin, 1968, and others).

TABLE 27



Linear Motion	A Direction of Acceleration		B Inertial Resulting by g-forces on the Body		
	Aviation Designation (System I)	Descriptive terms of Acceleration (System II)	Physiological terms (System III)	Physiological Designations (System IV)	Local Descriptive terminology
Forward	$+a_x$	Back to chest	Transverse A-P, supine, chest to back.	$+G_x$	Eyeballs "inward"
Backward	$-a_x$	Chest to back	Transverse P-A, prone, back to chest.	$-G_x$	Eyeballs "outward"
Upward	$-a_z$	Feet to head	Positive.	$+G_z$	Eyeballs "downward"
Downward	$+a_z$	Head to feet	Negative.	$-G_z$	Eyeballs "upward"
To the right	$+a_y$	To the right	Side to left.	$+G_y$	Eyeballs "left"
To the left	$-a_y$	To the left	Side to right.	$-G_y$	Eyeballs "right"

Arbitrary designations: Letter G is used as a unit to express the inertial force resulting in acceleration of the entire body multiplied by the value of acceleration of the force of gravity: $G_0 = 980.665$ cm/sec^2;

A-P, anterior-posterior; P-A, posterior-anterior.

The reaction of man to the effect of accelerations is determined by a number of factors among which particular significance attaches to magnitude, time of action, rate of increment and direction of g-force vector with respect

to the trunk, as well as to the original functional condition of the organism. Changes in the organism can appear from hardly detectable functional changes to extremely severe conditions accompanied by sharp disorders in the activity of organs of respiration, the cardiovascular system, the nervous system and other systems which can lead not only to loss of consciousness (Figure 58), but occasionally even to gross anatomical damages of the body.

The general condition of man during the action of accelerations is /293
characterized by the appearance of a sensation of weight throughout the body, painful sensations, at first by difficulty and then by complete absence of ability to move. Displacement of the soft tissues in a number of internal organs in the direction of action of the g-force occurs.

During the effect of longitudinal g-forces from head to seat ($+G_z$) visual disorders are extremely characteristic. During the action of g-forces from foot to head ($-G_z$) very strong painful sensations arise in the region of the head and the eyes and hemorrhages are possible in the conjunctiva of the eyelids and sclera. In animals, nose bleeds can appear and edema of the soft tissues of the neck and head can also develop. Sharp disorders of the cardiac rhythm during these g-forces are the basic limiting factor. During the effect of transverse accelerations, labored breathing up to total inability to inhale is possible with disorder of vision and the appearance of pain sensations in the epigastric and subpleural regions.

Depending upon the density of the internal organs, their place of location, and the elasticity of the tissue connecting them with surrounding tissues, the character of disorders which occur can vary. It is understandable that the most mobile tissue in the organism is the blood and tissue fluid. Therefore, disorders of the hemodynamics hold one of the leading places in the genesis of physiological changes during accelerations. However, certain significance also attaches to such factors as displacement of the internal organs and their deformation, causing not only disruption of the function of these organs, but also increased afferentation to the central nervous system, which frequently leads to disorders of its function.

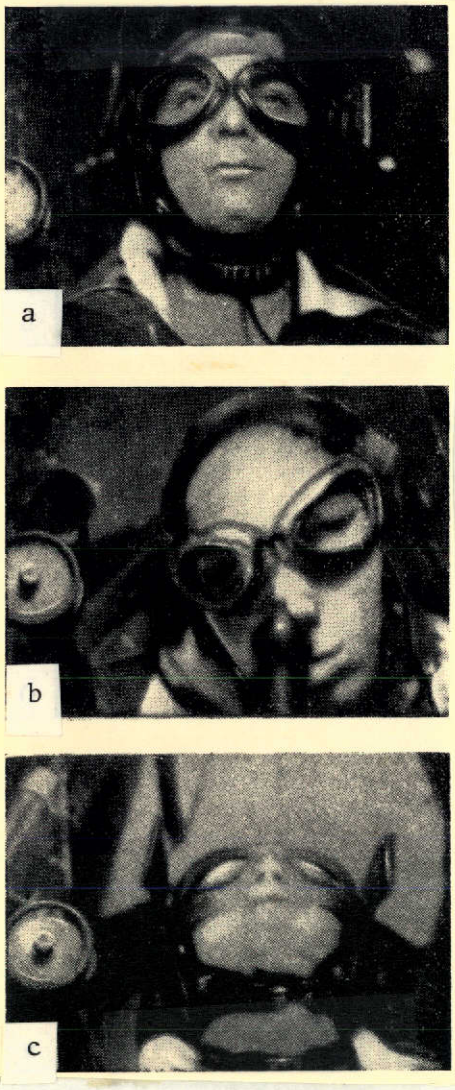


Figure 58. External View of a Man Under the Effect of G-Forces Acting in the Head-Seat Direction.

a, Prior to exposure to g-forces; b, During the effect of g-forces; c, Unconscious state.

The Central Nervous System and Vision

The functional condition of the central nervous system under the influence of acceleration has been studied both by the method of conditioned reflexes and through the intermediary of monitoring the bioelectrical activity of the brain. The first investigations in this regard were conducted by A. V Vinokurov et al. (1946) during flights aboard aircraft; they noted an increase in the latent period of response reaction to the supplied stimulus. The result of these observations on people were subsequently deepened in experiments conducted on the centrifuge by G. L. Komendantov et al. (1955). A. A. Bronshteyn and V. P. Zagryadskiy (1958) convincingly demonstrated in investigations performed on healthy people that accelerations of moderate magnitude cause release of the unconditioned reflexes and slight inhibition of the effector reflexes, while high magnitude g-forces cause pronounced inhibition of the conditioned reflexes. /294

According to the observations of a number of authors (A. S. Barer, 1962; B. M. Savin, Z. K. Sulimo-Samuyllo, 1958), restoration of the higher nervous activity occurs in wave-like fashion and with moderately high values of acceleration takes approximately 5 minutes.

There is significant interest in investigations performed on animals which permit one to study deeply the character and mechanism of disorders of the higher nervous activity which occur under the effect of acceleration. The experiments of S. I. Vinogradov et al. (1953) with the motor-protective conditioned reflexes and those of B. M. Savin and Z. K. Sulimo-Samuyllo (1958) with food reinforcement have made it possible to establish that changes with respect to the conditioned reflexes are observed at accelerations ranging from 1 to 8 G. Here it is primarily the process of internal inhibition which suffers; phase phenomena appear, but with high values of accelerations there is complete inhibition of the conditioned reflexes. It is important to note that at the onset of action of acceleration one observes an increase in excitability of the cerebral cortex. The results of these investigations have been confirmed and expanded in a number of studies by other authors (V. V. Usachev, 1956; P. V. Vasil'yev, M. A. Gerd, 1964; B. M. Savin, 1963, 1966; S. I. Nudman, 1967, and others).

The phase character of changes in the function of the central nervous system has also been noted according to the data of electrophysiological investigations (Jasper et al., 1956; O. G. Gazenko et al., 1963; A. N. Razumeyev, P. M. Suvorov, 1964; Vacca et al., 1965, and others). According to the investigations of G. V. Izosimov and A. N. Razumeyev (1962), in the first phase, which ensued immediately after the offset of the effect of accelerations, a reaction of EEG desynchronization was observed, i.e., a significant increase in the number of rapid potentials with a simultaneous decrease in their amplitude. In the reticular formation and the hypothalamus, synchronous oscillations having a basic rhythm of 5-6 per second increased. The second phase was characterized by the appearance of high amplitude slow waves (the EEG synchronization reaction). In experiments performed on rabbits, the third phase ensued only at accelerations higher than 6 G and signs of decompensation of the cardiac activity and respiration appeared in addition to a deepening of the synchronization of the bioelectrical activity of the cortex. During exposure to accelerations of a magnitude of 7 G, slow high amplitude waves appeared in the cortex and hypothalamus, while in the reticular formation a decrease in amplitude of the basic rhythm in comparison with the original data was recorded. Subsequently, in the potentials drawn from the

hypothalamus a significant change with respect to rapid oscillations was noted; slow waves predominated in the cortex while in the reticular formation the activity entirely disappeared. With a continuation of acceleration activity in all of the formations of the brain disappeared.

O. G. Gazenko et al. (1963) observed the appearance of a phase of desynchronization in investigations carried out on people during longitudinal accelerations of 3-4 G and transverse accelerations of 5-8 G. The phase "exaltation of alpha-rhythm" ensued under the effect of longitudinal accelerations of 5-7 G and transverse accelerations of 8-10 G. With a subsequent /295 increase in accelerations slow theta- and delta-waves began to predominate, as a rule directly preceding visual disorders.

The functional disorders, in a number of cases, have at their bases histochemical and histological changes described in the studies of V. P. Kurkovskiy (1953), D. I. Medvedev (1964), B. S. Glushkov (1965), Cooke, Barcroft (1965) and others.

In the period of aftereffects of accelerations, restoration in the cortex, then in the hypothalamus, and finally in the reticular formation was observed.

Hence, under the influence of comparatively low magnitude accelerations pronounced functional changes occur with respect to the central nervous system which are characterized by phase development, nonuniform and nonsimultaneous inclusion in the process of various formations of the brain. Naturally, the developed functional changes in the nervous system lead to disruption of its regulating and coordinating role which is accompanied by a decrease in working capacity of man.

Visual disorder under exposure to acceleration appears in the subjective sensation of a gray and then black shroud (Gauer, 1944; Diringshofen, 1933, 1942; I. Ya. Borshchevskiy et al., 1938; V. I. Babushkin et al., 1956, and others). One can arbitrarily distinguish three phases in the course of the visual disorders -- fogging and weakening of peripheral vision, then complete disappearance of peripheral vision and weakening of central vision, and finally, loss of central vision ("black shroud"). Many investigations of

Soviet and foreign authors have shown that in man during g-forces acting in the "head to food" direction ($+G_z$), the first phase of these disorders appears at 3.5-5 units, the second at 4-5.5 units, and the third at 4.5-6.5 units. The appearance of visual disorders during transverse accelerations (angle of inclination of the back of the chair at 80° to the vector of acceleration) is usually observed at 12-16 G. It is important to note that the auditory analyzer is more resistant to the effect of accelerations and can be used to relay the vital information to pilots and cosmonauts. The pathogenesis of disorders with respect to vision primarily consist in the disruption of hemodynamics of the brain and retina.

The Cardiovascular System

Disorders in the circulatory system during the action of accelerations are most significant; they hold the leading place in the genesis of physiological reactions. This is related to phenomena of redistribution of the circulating mass of blood. The degree of redistribution of blood and systemic changes in the hemodynamics are determined primarily by the direction of action of accelerations. The greatest changes in systemic hemodynamics occur during the action of "longitudinal" g-forces ($+G_z$, $-G_z$), and the least during the action of transverse g-forces ($+G_x$, $-G_x$), which is due to the location of the main blood vessels along the longitudinal axis of the body. During the action of g-forces from head to foot ($+G_z$), displacement of the blood mass from the blood vessels located in the upper part of the body to the blood vessels of the abdominal cavity and the lower extremities occurs. As the result of this redistribution of the blood, blood pressure in the blood vessels located below the level of the heart increases. Under these conditions the influx of blood along the veins to the heart will be labored and there will be a decrease in the amount of blood pumped out by the heart. As a result, anemia of the brain and a number of other sensory organs appears. This is accompanied by disorders of vision and can lead to loss of consciousness. /296
During the action of g-forces in the direction from the feet to the head ($-G_z$), displacement of blood occurs in the reverse direction, due to which blood accumulates in the upper part of the trunk and blood pressure above the level of the heart sharply increases.

Changes in the systemic hemodynamics during the action of transversely directed g-forces are significantly less pronounced than during longitudinal. However a strictly transverse attitude with respect to the vector of accelerations is practically used very seldom, since in most cases man is in a posture with a certain inclination of the back of the chair, which also creates a "longitudinal" component. It is in fact this component during the action of transverse accelerations which determines the magnitude of changes in the systemic hemodynamics. Moreover, it is necessary to take into account that many organs and tissues of the body have an extremely richly developed network of blood vessels with a more or less uniform distribution of them in all directions. Therefore shift of the blood within the limits of any particular organ will appear with any direction of inertial forces, which can lead to regional disorder of the circulation [for example, as the result of the transverse component of g-forces ($+G_x$), redistribution of the blood in the system of the pulmonary blood vessels from front to back occurs].

Ranke (1937), Armstrong, Heim (1938) and other investigators revealed a direct relationship between the magnitude of g-forces and the degree of drop in pressure in the carotid artery under the action of g-forces (Figure 59). X-ray observations made it possible to establish that the shadow of the heart and the large blood vessels becomes paler, indicating a decrease in blood volume of the heart's chambers. After cessation of rotation, an acute short term expansion of the heart appears as the result of a sharp increased influx of blood to it. Simultaneously, with g-forces ($+G_z$), various investigators observed lightening of the upper lobes of the lung and an increase in darkening in the lower lobes (A. R. Mansurov, 1956, 1958), and with g-forces ($+G_x$) lightening in the anterior lobes and darkening in the posterior lobes of the lung (A. R. Mansurov et al., 1961; K. I. Murakhovskiy, 1967; Cherniak, Hyde et al., 1961, 1962; Meueller, 1961).

It is important to note that during the action of longitudinal g-forces ($+G_z$) a clearly defined correlation was established between the level of arterial pressure in the blood vessels of the ear, the condition of visual perception and the subsequent development of unconsciousness. The same correlation also exists with transverse g-forces ($+G_x$) at an angle of 20-25° or

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more from the horizontal, when systemic circulatory disorders of the hemodynamics as the result of the "longitudinal" component ($+G_z$) play a leading role. In the optimal posture (at an angle of 10-12°), the hemodynamic changes are of a predominantly regional character. As a result of this, with maintenance of consciousness and an adequately high level of blood pressure in the blood vessels of the ear, complete loss of vision is possible.

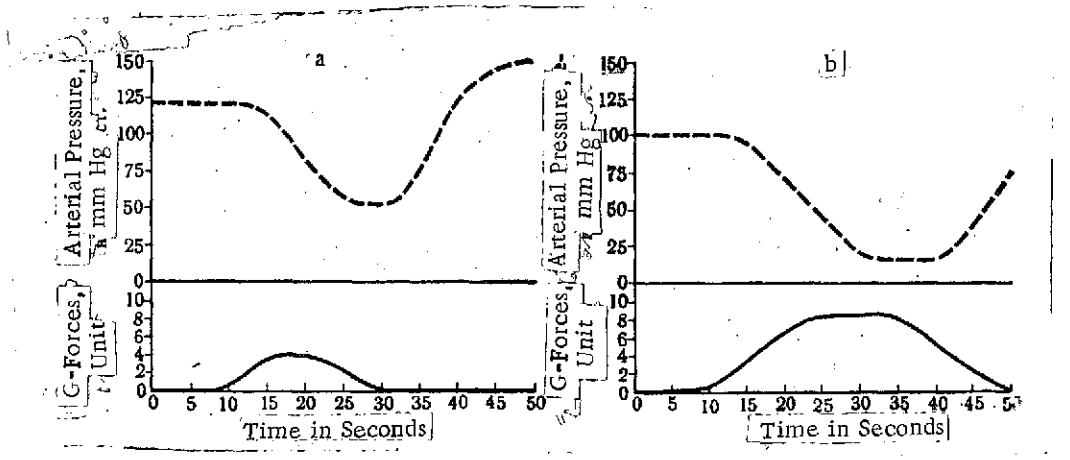

Figure 59. Drop in Blood Pressure in the Carotid Artery Under the Influence of G-forces in the Head to Seat Direction, Magnitude 4 Units (a) and 8 Units (b) (after Armstrong, 1952).

Complex restructurings in the system of hemodynamics with the inclusion of compensating mechanisms lead to an increase in the frequency of cardiac contractions. In man, dependent upon the magnitude of g-forces, the frequency of cardiac contractions reaches 130-180 beats per minute and rarely 190 beats per minute or more. Available materials do not permit one to reveal the correlation between the degree of hastening of the cardiac rhythm and tolerance of g-forces. Moreover, it has been established that a breakdown in compensation can ensue at different frequencies of the cardiac contractions. At the stage of compensation the systolic volume of blood during g-forces ($+G_z$) decreases, however as a result of the frequency of the cardiac rhythm the minute volume of blood in healthy people at g-forces up to 5 units even increases (P. M. Suvorov, 1969). During this process one observes an increase in the volumetric rate of blood output by the left ventricle, which is explained

by an increase in the power of the cardiac contractions. At the stage of decompensation a drop occurs not only in the systolic, but also in the minute volume of blood.

The condition of vascular tonus in the mechanism of compensation of functions of the organism during g-forces plays an important role. Thus, a drop in power of cardiac contractions can be the result of an inadequate influx of circulating blood to the heart caused by the characteristics of peripheral resistance which depend upon the condition of vascular tonus. During exposure to transverse g-forces ($\pm G_x$), significant changes in the hemodynamics of the lesser circulation occur which consist in redistribution of the blood in the system of the pulmonary artery under the action of g-forces (A. A. Kiselev, 1962, and others). Hyde (1961) considers that conditions of disruption of circulation in the lesser circuit lead primarily to disorders of absorption of O_2 from the alveolar air into the blood.

Electrocardiographic investigations have made it possible to reveal, on the one hand, the changes caused by change in the location of the heart during the effect of g-forces, and on the other hand -- various disorders in the cardiac rhythm and signs characteristic of coronary insufficiency (Figure 60).

The most frequent form of disorder of the cardiac rhythm is extrasystole of different types. In exceptionally rare cases seizures of paroxysmal tachycardia have appeared (Clark et al., 1959; P. M. Suvorov, 1969). Over the course of many years of observations we have determined only one case of appearance of paroxysmal tachycardia which occurred against a background of compensation disruption. During the action of transverse accelerations, disruptions of normal conditions of hemodynamics in the lesser circuit and decreased in blood oxygen saturation enable one to speculate that the heart can be under conditions of hypoxemia. Steiner and Meueller (1960) consider that in the case of g-forces ($+G_x$) the development of ischemia of the myocardium is possible, which in Meueller's opinion (1961) can lead to the appearance of chest pains. A clear cut relationship of the content of O_2 in the arterial blood and the blood of the coronary sinus with the magnitude and duration of action of transverse g-forces ($+G_x$) has been shown by A. D. Voskresenskiy (1963). The heart's consumption of oxygen increases, which decreases the

content of O_2 in the blood of the coronary sinus with a simultaneous increase in the outflux of blood from the sinus. Maintenance of an adequately high level of coronary blood flow is apparently the primary factor compensating for the growing requirement of oxygen for the myocardium. /298

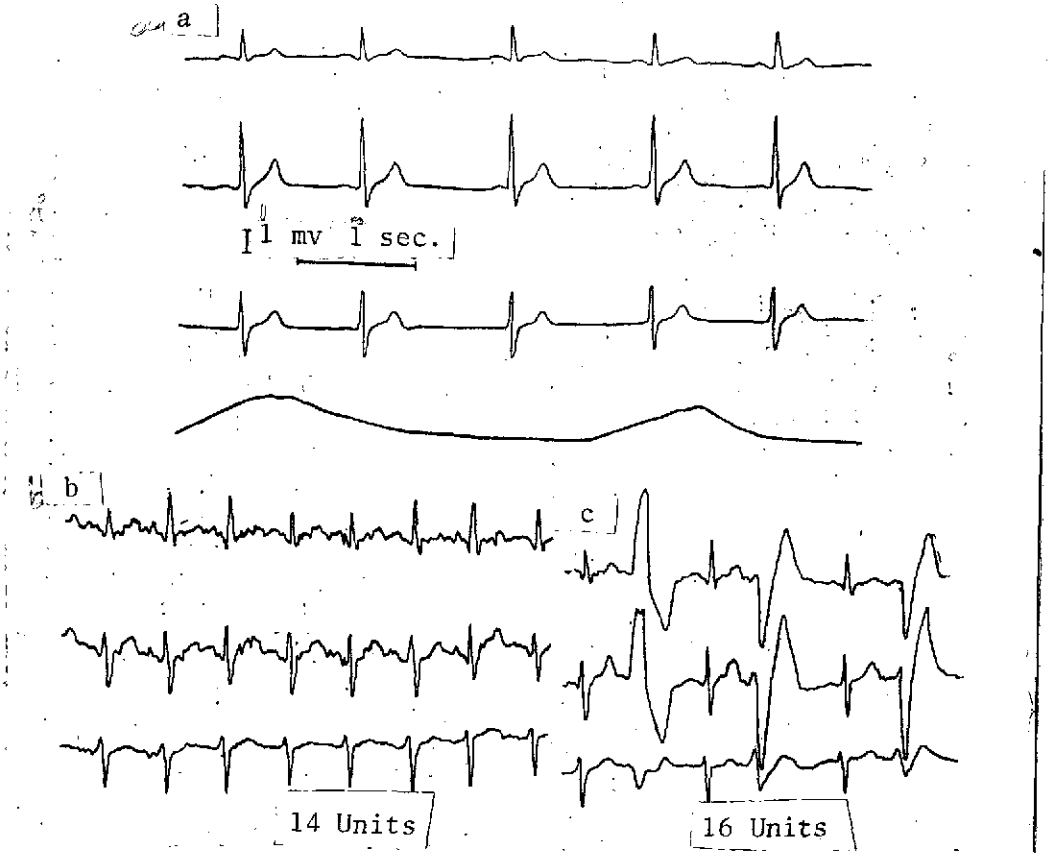

Figure 60. Change in ECG of Man During the Action of G-Forces in the Chest to Back Direction. Angle of inclination of the chair back is 65° to the vector of acceleration, rate of increment of acceleration 0.2 sec.

a, Before exposure; b, During the action of g-forces having a magnitude of 14 units; c, During the action of g-forces having a magnitude of 16 units, in the period of unconsciousness. On the ECG, phenomena of sinus tachycardia; one can see a decrease in the amplitude of the R spike, its alternation (b); in the period of unconsciousness -- bradycardia, polytopic extrasystole, displacement of the S-T inverval (c).

Morphological investigations of the heart during the action of transverse accelerations have made it possible to detect anemia, and in a number of cases

hemorrhages, edema and dystrophy of the cardiac muscle (V. G. Petrukhin, M. M. Sokolov, 1963, and others). It is interesting to note that one observes a certain relationship of the degree of disruption of the cardiac activity and the content of glycogen in the myocardium and liver (V. Ye. Belay et al., 1967). True, the authors with good basis consider that disruption of the carbohydrate metabolism in the myocardium is not the single cause for exhaustion of the adaptive mechanisms of the cardiac activity.

Respiration and Gas Exchange

The effect of accelerations on the function of external respiration is determined not only by the magnitude and time of action, but also by the direction of the vector of accelerations with respect to the vertical axis of the body. During the action of longitudinal g-forces ($+G_z$), pulmonary ventilation increases as the result of both an increase in the depth and frequency of respiration. An increase in the respiratory volume apparently depends upon flattening of the diaphragm under the influence of longitudinal g-forces. The application of a g-suit, causing an increase in intraabdominal pressure makes possible a decrease in respiratory volume. /299

According to the data of P. K. Isakov (1957), V. I. Babushkin et al. (1958), and P. M. Suvorov (1968) and others, the minute volume of respiration (MVR) during g-forces ($+G_z$) increases with respect to the original magnitude by more than three times. There is an increase in the consumption of O_2, the elimination of CO_2, and there is an increase in the respiratory coefficient (RC). X-ray investigations conducted on animals and people showed lightening of the pulmonary picture in the upper lobes of the lungs and darkening of the picture in the lower regions. Here the overall transparency of the lungs diminished (Fisher, 1957; Dirinsghofen, 1938; Gauer, 1944; A. R. Mansurov, 1958; K. I. Murakhovskiy, 1967). According to the data of Brayn and Machamara [sic] (1965), the flow of blood in the upper lobes of the lungs stops during the action of accelerations of a magnitude of 6-7 G, it remains unchanged in the midportions of the lungs, while in the lower portions edemas and atelectases form. Consequently, notwithstanding an increase in respiratory volume and MVR, the action of g-forces ($+G_z$) can cause the phenomenon of hypoxia and hypocapnia.

The deepest disorders in function of external respiration are observed during transverse accelerations. Disorders of respiration during transverse accelerations frequently are of leading significance in the general symptoms complex of disorders and are caused by changes in the biomechanics of the respiratory act; they are also caused by disorder of circulation in the blood vessels of the lesser circuit. Increasing external pressure resulting from the effect of the transverse component of accelerations cause the deformation of the thoracic cavity, changes the ordinary arrangement of organs in it and leads to labored accomplishment of the normal respiratory act (Armstrong, 1938; D. V. Sobol', 1947; A. R. Mansurov, 1956; 1958; Hershold, 1960; K. I. Murakhovskiy, 1967, 1968, and others). One observes an increase in respiration, lengthening of the inspiration phase and shortening of the expiration act as well as gradual decrease in its depth. The vital pulmonary capacity (VPC) decreases with increase in g-forces (Figure 61). /300

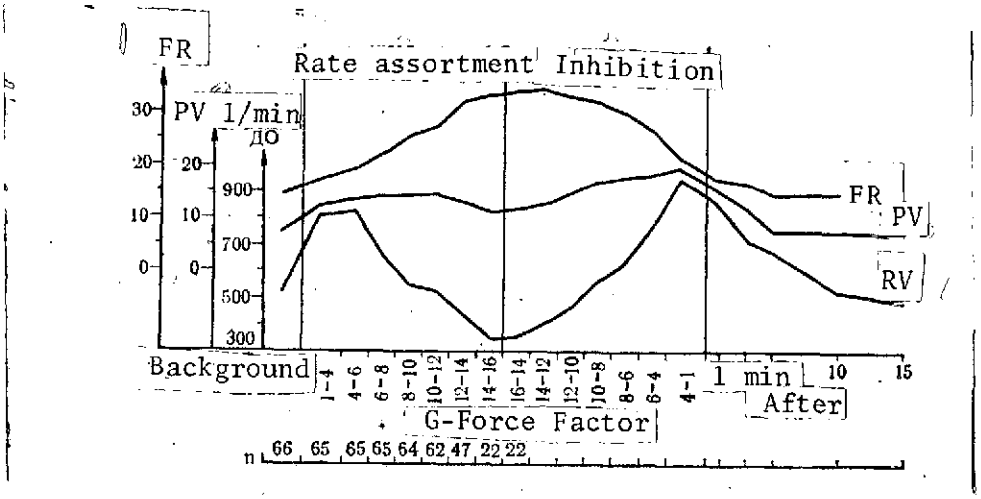

Figure 61. Dynamics of Change in Certain Indices of External Respiration During the Action of Transverse G-Forces in the Chest to Back Direction (after S. F. Simpura).

Average data. Posture of man at an angle of 80° to the vector of accelerations. Rate of increment of accelerations 0.2 units/sec. Regime of action of the g-forces "peak like", n, Number of people; FR, Frequency of respiration; PV, Pulmonary ventilation; RV, Respiratory volume.

It should be noted that changes in the indices of volume of respiration and gas exchange are not only determined by the individual characteristics of human resistance to the effect of g-forces, but also by the characteristics of the effect of the latter (the rate of increment of accelerations, the regime of action of the "area" or "peak like" types). The effectiveness of ventilation in the lungs, i.e., the amount of oxygen absorbed by the lungs from one liter ventilating air decreases with an increase in g-forces (Figure 62, a). After the action of g-forces the restorative period is characterized by the elimination of oxygen debt and by the elimination of the excess carbon dioxide gas, i.e., excess in relation to the original level. The oxygen debt is determined by the magnitude of effect and before g-forces of 16 units is directly dependent upon it (Figure 62, b). Disorders in the rhythm of respiration (its delay for a period of 10-25 sec) in g-forces of up to 13 units does not cause significant changes with respect to the function of respiration and gas exchange; during g-forces of up to 16 units there is noticeable deterioration in the effectiveness of ventilation and gas exchange in the lungs. With even greater magnitudes of action, apparently, it is expedient to lower ventilation of the lungs since a significant oxygen consumption of the respiratory musculature leads to an "unprofitable" system of respiration, on the whole (A. S. Barer et al., 1967).

The action of g-forces leads to nonuniform ventilation of different regions of the lungs and creates conditions for nonuniform distribution of blood flow. The ventral regions of the lungs are adequately ventilated but are poorly supplied with blood, while the dorsal, on the other hand, are plethoric but are poorly ventilated. Unequal ventilation and blood supply in the lungs creates conditions for arterial-venous shunting of blood /301 (Steiner, Meueller, 1961; Zechman, Taylor, 1962; Gauer, Zuidema, 1961, and others), which is an adaptive reaction easing pulmonary circulating under conditions of capillary congestion. Together with this, this reaction is one of the causes of hypoxia, since a certain part of the venous blood which is not entirely saturated with oxygen enters the arterial tree.

A decrease in the content of oxygen in the blood during the action of transverse g-forces ($+G_x$) in combination with circulatory disorders (systemic

and regional) can lead under certain regimes of g-forces to disruption of the oxygen balance of the organism and to the development of hypoxia (A. S. Barer, G. N. Golov, Ye. N. Sorokin, 1963; Ye. N. Sorokin, 1969; P. V. Vasil'yev, A. R. Kotovskaya, 1965, and others). Investigations conducted by the aid of the polarographic method (Ye. A. Kovalenko et al., 1963; Ye. N. Sorokin, 1966, and others) detected a decrease in the oxygen content in brain and heart tissues in animals, with a change of the oxidation-reductive equilibrium toward under-oxidation.

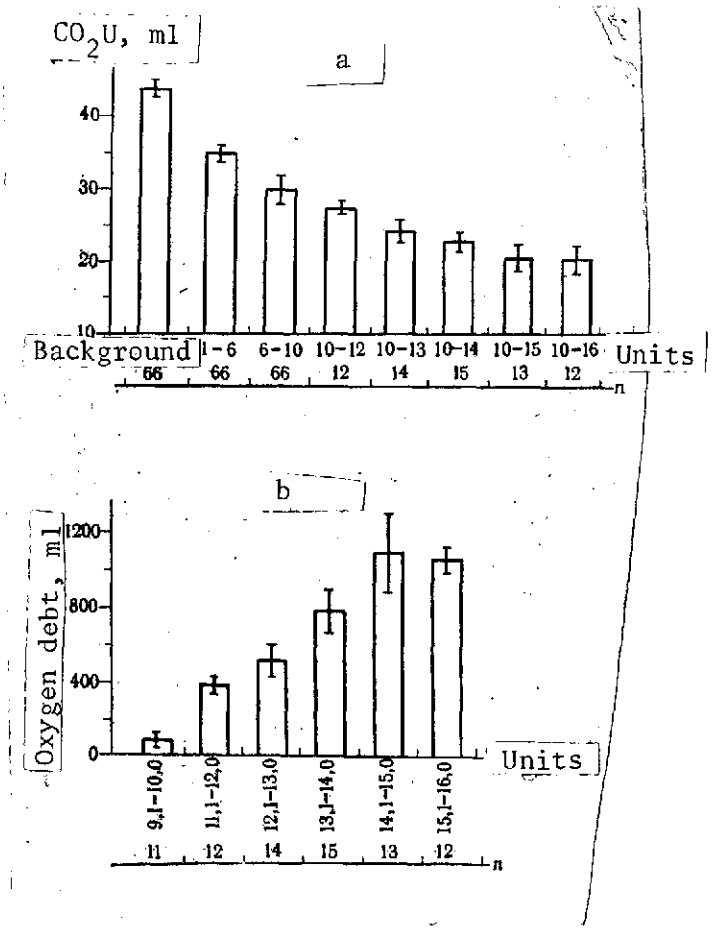

Figure 62. Coefficient of Oxygen Use and Oxygen Debt. Average data and the establishing interval are given; regime of action of g-forces is "peak like", rate of increment is 0.2 units/sec; posture 80° to acceleration vector. a, Coefficient of oxygen use in the lungs corresponding to g-forces varying in magnitude in the chest to back direction; b, Oxygen debt in the period of after effects of transverse g-forces ($+G_x$) of different magnitudes.

The results of our investigations indicated the effectiveness of alveolar ventilation, the degree of oxygen debt and the rate of its liquidation depend not only on the regime of g-forces, but also on physical and special conditioning of subjects. During a morphological investigation, changes of the congestive hyperemic type, with perivascular edemas, hemorrages and atelectases were found in the lungs (Ye. F. Kotovskiy, 1963; Yu. N. Korolev, 1963, 1965; V. G. Petrukhin, 1963, and others).

The Gastrointestinal Tract and the Kidneys

The effect of acceleration on the function of the organs of digestion and excretion has been inadequately studied. A. A. Sergeyev

(1957) cites data to the effect that in experiments performed on animals, delay in the evacuation of the contents of the stomach was observed even following acceleration moderate in magnitude. Here a direct relationship was noted with respect to the duration of the delay of food mass in the stomach and the magnitude of g-forces.

The most interesting materials were obtained in the work of P. M. Suvorov (1958) who studied the effect of positive and negative accelerations on the evacuating function of the stomach and also on the secretory function of the salivary, gastric and intestinal glands. He established that the effect of longitudinal accelerations ($+G_z$, $-G_z$) caused inhibition of hunger contractions of the stomach in the dog for a period of 1-1.5 hours, after which a gradual restoration of periodic activity of the stomach was observed.

The character and direction of changes in the secretion of glands of the digestive tract during positive (7-9 units for a period of 20 seconds) and negative (3-5 units for a period of 20 seconds) g-forces are similar. These changes consist in an initial inhibition of secretion which is subsequently replaced by a period of stipulation having varying duration. The increase in intestinal secretion is observed ranging from several days to several weeks. These results of experiments were confirmed in the investigations of V. Ye. Potkin (1966), who studied the secretory function of the small intestine, predominantly during transverse g-forces. However the degree of expression of noted changes both with respect to duration and with respect to enzymatic activity during transverse g-forces was less than during longitudinal g-forces.

In investigations performed on people (P. M. Suvorov, 1958, 1959, 1960), /302
with g-forces of 3-5 units, a phase nature of secretory reaction was also observed with initial inhibition and subsequent stimulation. The motor activity of the stomach with these magnitudes of radial accelerations did not significantly change.

In experiments with repeated exposures to g-forces over 4-5 days, the development of adaptation phenomena was observed. There was a significant decrease in the time of inhibition of salivary secretion, a lesser decrease in dense residue in saliva and changes with respect to amylase activity were absent.

The primary genesis of the noted changes with respect to the secretory--motor function of the gastrointestinal tract is seen by many authors to be a disruption of interactions of tonus of the sympathetic and parasympathetic nervous system.

During an examination of the effect of g-forces on the activity of the digestive glands, the study of S. A. Bugrov (1965) deserves attention. S. A. Bugrov first conducted a systematic investigation of digestive juice secretion and enzymatic secretory functions of the pancreas in the period of after-effects of transversely directed accelerations. In experiments performed on dogs the author demonstrated that during the action of g-forces in a magnitude of 8 units (for a period of 3 minutes) there is disruption of the external secretory function of the pancreas. Hypersecretory periods alternate with hyposecretory periods and the character of the secretory reaction to food stimulus is altered; there is disruption in the composition of the secretion. Restoration of the function of the pancreas is delayed up to 4 weeks or longer. The fact of adaptive reactions of the pancreas during repeated exposures to g-forces which was noted by the author seems important.

Hence, under the effect of even comparatively low magnitudes of g-forces significant disruptions of functions occur with respect to a number of organs of the digestive tract; these disruptions have at their bases a number of structural and biochemical changes (Yu. N. Kopayev, 1966, 1969; V. G. Yeliseyev, 1966; Ye. F. Kotovskiy, I. F. Nikolayeva, 1965, and others).

Somewhat more attention was paid to a study of the effect of accelerations on the function of the kidneys.

I. Ya. Borshchevskiy et al. (1938) established that in pilots who had been subjected to the action of g-forces in a magnitude of 6-8 units, erythrocytes were frequently detected in the urine, while in certain cases there were granular cylinders. Similar results were also obtained in experiments conducted by a number of authors on animals under conditions of their rotation in centrifuges (Senelar et al., 1959). In specially conducted investigations on rats in a study of diuresis following the effect of radial acclerations of a magnitude of 2-5 units, it was established that in animals polyuria developed which was maintained for a period of 5-6 hours; there was also a significant decrease in the concentration of chlorides in the urine (A. A. Sergeyev, 1957).

However in the experiments of Stauffer and Errebo-Knudson (1950) directly contradictory results were obtained. With positive g-forces at a magnitude of only 3 units the amount of excreted urine following water loading decreased from 12.5 ml/min to 7.5 ml/min, while the specific gravity of urine increased from 1.0008 to 1.0036. Similar data were also obtained during transverse g-forces, but under these conditions oliguria developed only after g-forces of 7 units or more.

In investigations conducted by us on dogs with separately removed urinary ducts using the method of L. A. Orbeli, it was established that directly following g-forces of 5, 8 and 12 units short term oliguria was observed, immediately after which increased diuresis ensued (P. V. Vasil'yev et al., 1967). The degree of these changes were determined to a significant extent by the magnitude of g-forces. Under the influence of 12-time exposure to g-forces there was a sharp increase in urinary excretion, an increase in the excretion of potassium and sodium, and a significant increase in reabsorption of osmotically free water. However the described changes, as a rule, normalized after only 1.5-2 hours. The results of experiments with water loading indicate that under conditions of duplicated g-forces the capacity of the kidneys to excrete water does not change. There is no disruption in the function of the kidneys with respect to hypotonization of urine, reabsorption of potassium and sodium from urine, as well as the other indices of renal function. Protein in the urine appeared in small amounts and disappeared from it after 1.5-3 hours. In the urinary precipitate leucocytes, epithelial cells and fresh unleached erythrocytes were noted. /303

An analysis of the data obtained by us enables us to express the hypothesis that the described changes were primarily caused by activation of the hypothalamo-hypophysary system. It is in fact these very mechanisms which are given an important place by Watson and Rapp (1962) in changes of the renal function. The authors view the volume receptors of the blood vessels of the thoracic cavity, which are stimulated when the blood vessels are plethoric in the capacity of an activating mechanism. Under the influence of g-forces, just as in our experiments on dogs, they observed mild transient increase in glomerular filtration following short term (20-35 minute) inhibition of diuresis.

Under the influence of g-forces, morphological changes develop in the kidneys of experimental animals (V. G. Petrukhin, M. I. Sokolova, 1963; V. V. Korolev, 1964, and others), which, as a rule, are of a transient nature during single exposures.

In summarizing the facts stated above, one could expect that in the case of large magnitude g-forces the following two primary processes will occur: an increase in glomerular filtration and a decrease in reabsorption of salts. The first of these effects can develop from a change in the renal hemodynamics, while the second arises as the result of the direct effect of g-forces and hypoxia induced in the renal cells.

Mechanisms of the Effect of Accelerations on the Organism

As one can see from the material cited above, exposure of the organism to g-forces has as its consequence functional and morphological changes with respect to various systems of the organism. The most important direct effects of the action of acceleration consist in redistribution of the blood in the vascular system, disruption of respiration, displacement of the organs and deformation of tissues. Dependent upon the direction of the vector of acceleration, the specific significance of these three primary mechanisms of the effect of accelerations changes. Thus, during longitudinal accelerations the basic element in the genesis of the developing disorders is circulatory hypoxia of the brain.

During transversely directed accelerations, primary position in the mechanism of disorders is held by disorders of external respiratory function.

Disorders of respiratory function and hemodynamic disorders lead to hypoxemia and hypoxia of the most important organs and tissues of the organism, primarily the brain and the heart (V. I. Danileyko, 1962; A. R. Kotovskaya et al., 1962; Ye. A. Kovalenko et al., 1963). Against this background the altered flow of afferent impulsation (V. M. Savin, 1965) makes possible the appearance of disorders of central regulation, which in their turn decrease the compensator-adaptive capacities of the organism. The changes in function of /304
the endocrine glands, which appear under the influence of disruptions in the regulatory activity of the central nervous system and hypoxia, lead to even greater disorders with respect to various systems of the organism.

The primary elements in the mechanism of influence of accelerations on the functional systems of the organism are presented in a systematized form in Figure 63.

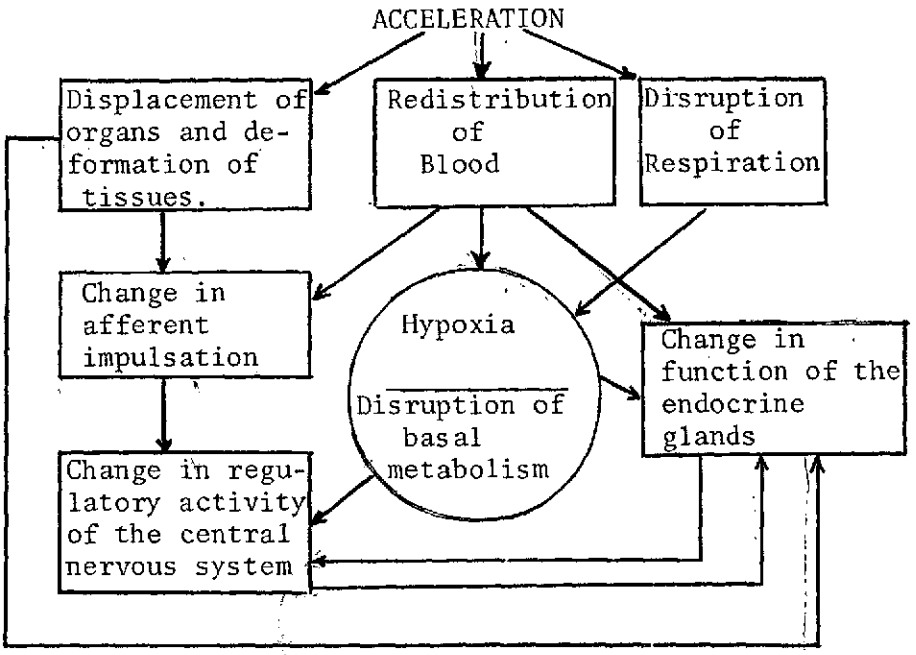
ACCELERATION
Displacement of organs and deformation of tissues.
Redistribution of Blood
Disruption of Respiration
Change in afferent impulsation
Hypoxia
Disruption of basal metabolism
Change in function of the endocrine glands
Change in regulatory activity of the central nervous system

Figure 63. Diagram of the Most General Mechanisms of the Effect of Accelerations on the Organism.

In a number of situations accelerations act as an extremal stimulus which can deeply disrupt the normal course of vital processes and exert an injurious and even destructive effect on biological objects.

D. Ye. Rozenblyum (1967), with every basis in fact, discerns two phases of reaction to the effect of g-forces. The first phase is characterized by compensator changes in the organism when some functions, predominantly the vital ones, are enhanced while others are temporarily suppressed for adaptive reasons, and still others are to some extent disrupted. In the second phase (the decompensation phase) one observes suppression and inhibition of vitally important systems of the organism. Thus, for example, in the first phase one observes an increase in the cardiac contractions, elevation of blood pressure, increase in the minute volume of the heart and regional blood flow, pulmonary ventilation, oxygen consumption, and an increase in oxygen tension

in the brain tissues. At the same time there is an increase in the function of a number of endocrine glands which one can evaluate according to the clearly pronounced change in the composition of the peripheral blood and by the increased content of cholesterol in the blood, and by other indicators (M. M. Korotayev et al., 1968; Yurina, N. A., 1965, and others). The character of changes in the metabolism of histamine, adrenaline, acetylcholine, potassium, and sodium in response to accelerations of low or moderate magnitudes are viewed by A. S. Barer et al. (1959) as an indication of adaptive reactions. /305

The onset of the second phase is characterized by the disruption of compensation, which is manifested by relative or absolute bradycardia, disruption of the cardiac rhythm and capacity, by a decrease in arterial pressure, disruption of the oxidation-reduction processes in the vitally important organs (Ye. I. Sorokina, 1966), by disorder of the regulator function of the nervous and endocrine systems, etc. All this leads to profound functional and morphological changes not only in the epiorgan and tissue levels, but also at the cellular and subcellular levels (A. S. Barer et al., 1968).

During long term action of even greater g-forces sudden death can occur, in most cases as the result of cardiovascular or respiratory insufficiency.

The Limits of Tolerance of Accelerations

Man is least resistant to the effect of g-forces in the seat to head direction ($-G_z$), and most resistant to g-forces acting along the chest to back direction ($+G_x$). With strictly transversely directed g-forces tolerance to them is practically limited to a magnitude of 8 units due to severe difficulties in breathing and strong pain sensations. Elevation of the back of the chair to 25° (from the horizontal) increases the boundary of tolerance to 12-14 units. However in this regard the primary limiting factors are disruption of systemic hemodynamics and respiration. A decrease in the value of the angle to 10-12° significantly expands the boundary of human tolerance to accelerations (A. R. Kotovskaya et al., 1962; A. S. Barer et al., 1964; Hyde, 1961, and others).

The significance of varying rates of increment of g-forces is shown in Figure 64. As one can see from this figure, the maximum tolerable magnitude

of transverse g-forces ($+G_x$) at a rate of increment of 0.1 unit/sec comprise 12 units on the average, at 0.2 unit/sec -- 14 units; at 1 unit/sec -- 26 units.

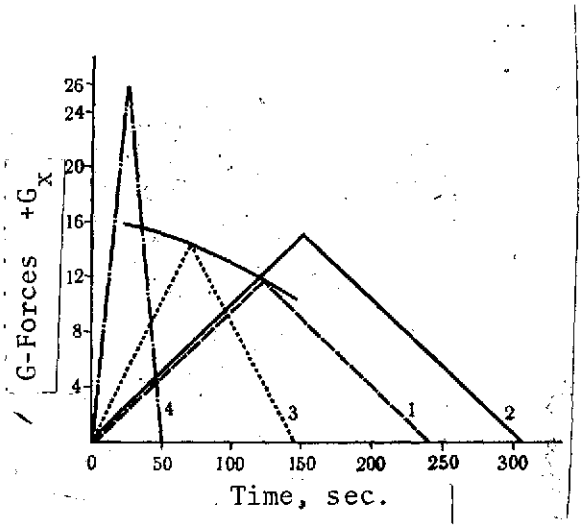

Figure 64. Human Tolerance to G-Forces of a "Peak Like" Character Acting in the Chest to Back Direction at Different Gradients of Increment (according to data of Soviet and foreign investigations).

1, 0.1 unit/sec; 2, 0.1 unit/sec (following a special training cycle of rotation on the centrifuge); 3, 0.2 unit/sec; 4, 1 unit/sec. Transverse line corresponds to magnitudes of g-forces at which visual disorders ensue.

The individual resistance of man to accelerations is determined by the initial functional condition, age, health, the degree and nature of development of the muscular system and conditioning for g-forces. The lowest tolerance to g-forces ($+G_z$) and at the same time the high lability of physiological functions, according to the data of P. M. Suvorov (1969), is observed in the age group 20-24 years. By 30-39 years of age resistance to g-forces increases and once again decreases in the age group 40-49. /306

Different deviations in the state of health have great significance with respect to tolerance to g-forces. According to the materials of P. M. Suvorov (1969), the lowest resistance to g-forces ($+G_z$) is noted in persons having signs of vascular-vegetative instability. The basic reason for diminished tolerance among such persons is disruption of regulation of the vascular tonus.

The muscular system has great significance in the development of the compensative reactions of the organism. The tension of the muscles of the abdominal press and those of the shoulder region increases the resistance of the organism to g-forces ($+G_z$) on the average by 1.8 ± 0.3 units. Moreover,

it has been established that sportsmen tolerate g-forces significantly better than others ($+G_z$ $+G_x$). Most promising from the viewpoint of increasing resistance to g-forces are sports exercises in which static loads predominated (Ya. A. Egolinskiy, M. M. Bogorad, 1962; V. I. Stepentsev, A. V. Yeremin, 1969; P. V. Vasil'yev, N. N. Uglova, 1967; P. M. Suvorov, 1969). The effectiveness of developing adaptive reactions of the organism to the effect of g-forces is also determined by the degree of training. Thus, pilots of fighter aviation have higher resistance to longitudinal g-forces than do untrained people.

It is known that immersion in water and long term stay in the horizontal position with limited movement or laboratory models of weightlessness in which circulatory and dynamic effects of its action are duplicated. It has been established that tolerance to g-forces ($+G_x$) of the peak like variety following hypodynamia of 7-60 days duration decreases by 2 units, on the average. During this process a strict correlation between the degree of decrease in resistance and the duration of hypodynamia was not established (A. R. Kotovskaya et al., 1964, 1965, 1967).

The influence of the composition of the gas atmosphere on human tolerance to g-forces has been extremely inadequately studied. It is known that compensated values of hypoxia by the organism do not significantly affect the level of tolerance to g-forces. More significant hypoxia leads to a decrease in resistance to g-forces (Diringshofen, 1938; V. A. Vinokurov et al., 1946; Gauer, 1944; V. B. Malkin, V. V. Usachev, 1955). A deterioration in tolerance to transverse g-forces ($+G_x$) was established by A. S. Barer et al. (1968), who studied the total effect of hypoxia and g-forces. Breathing pure oxygen yielded a positive effect. Increasing resistance to longitudinal g-forces ($+G_z$) also ensued when breathing air with a 4-6% content CO_2 as the result of reducing hypocapnia which appears due to hyperventilation (Ruff, 1938; Matthes, 1940).

The temperature factor has a great influence on the resistance of man to accelerations. A low ambient temperature makes possible increased tolerance to acceleration while a high ambient temperature decreases tolerance to accelerations (Martin, Henry, 1951; Burgess, 1959; A. A. Sergeyev, 1967).

Methods and Means of Increasing Tolerance to g-Forces

The problem of finding means of increasing the organism's resistance to long term exposure to accelerations has acquired practical significance since further increasing the power of motors and maneuverability of aircraft has become limited by the thresholds of physiological tolerance of the human organism. The solution of this problem would make it possible to alter flight /307
regimes in aircraft and regimes of placing spacecraft in assigned orbits, thereby making it possible more effectively to use the power of engines and to increase the working capacity of crew members in the period of placing the spacecraft in orbit and during their descent to the Earth. It will also make possible more reliable protection in the case of appearance of emergency situations.

The solution of the problem of prophylaxis of disorders and increasing resistance to g-forces is being accomplished in the following ways:

1) physical methods of increasing resistance consist in creating compensating g-suits; special chairs which make it possible to give an optimum position to man with respect to the vector of accelerations; individually profiled couches; the use of breathing under increased pressure and immersion systems of different types;

2) physiological methods of increasing resistance include nonspecific types of physical training and overall hardening of the organism; decreasing the reactiveness of the organism by means of pharmacological substances or cooling of various degrees; increasing the resistance of the organism by means of stimulating its compensative-adaptive mechanism using pharmacological preparations;

3) combined methods of increasing the resistance of the organism which consist of different combinations of the means indicated above.

Each of the enumerated methods have their own advantages and deficiencies.

In 1943 the first types of g-suits were suggested; these g-suits interfered with the redistribution of blood under the influence of the forces of gravitation. Their development was based on the fact that the primary pathogenic element during the action of positive g-forces (head to seat) is

redistribution of the blood from the head and upper regions of the trunk to the blood vessels of the abdominal cavity and lower extremities. Today, both in our country and abroad, several variations of g-suits are used. The principle of their action in all cases consists in automatically increasing pressure in the effected region of the stomach, thigh and shins by means of rubber compartments during increased g-forces (P. V. Vasil'yev, A. R. Kotovskaya, 1966).

The application of g-suits during g-forces in the head to seat direction ($+G_z$) has a favorable effect on the condition of many functions. Arterial pressure in the carotid and brachial arteries and also in the ear lobe were maintained at a higher level; there was an improvement in the inflow of blood to the brain and heart and lesser changes were observed with respect to vision, bioelectrical activity of the myocardium and the conditioned reflexive activity.

Tests of g-suits during rotation in the centrifuge, and also during flights aboard aircraft by various criteria of evaluation produced different results (resistance increased by 1.8-2.5 G). Notwithstanding many design attempts, a further increase in the effectiveness of g-suits is improbable. Moreover, the use of such suits is useful only with one direction of action of the g-forces -- head to seat. It is necessary to seek other ways of increasing the tolerance to accelerations (P. V. Vasil'yev, A. R. Kotovskaya, 1966).

As was indicated above, greatest tolerance to g-forces is observed with a transverse direction of their action with respect to the vertical axis of the human body.

As the result of conducting special investigations directed toward finding the most optimal posture for man during exposure to g-forces, it was established that strict observance of the ratio of angles of inclination of the chair back and the head rest with respect to the vector of g-forces is necessary, and one must also observe the same ratio with respect to the thigh and shins with regards to the trunk. Here the position of the trunk and head are most significant. /308

According to the observations of Bondurant et al. (1958), best tolerance was in a case in which the chair back was located at an angle of 65-70° with respect to the direction of g-forces. In subsequent studies based on factual physiological investigations conducted by both Soviet and foreign authors, it was established that the optimum inclination of the chair back is an angle of 70-80° with respect to the vector of accelerations (A. S. Barer et al., 1964; A. R. Kotovskaya et al., 1962; Clarke, Grey, 1961). According to the observations of A. S. Barer et al. (1964), g-forces of 12 units with a direction vector of accelerations at an angle of 80° were tolerated 2-3 times longer than at 65°. The reaction of the cardiovascular and respiratory systems in the first case was less tense which was due to higher resistance of the organism on the whole to the effect of g-forces.

Increasing the organism's tolerance in the optimum human posture with respect to the vector of accelerations can be achieved through the intermediary of creating individually profiled couches providing a high area of counterpressure to the acting forces. According to the data of Clarke and Grey (1961), tolerance to g-forces under these conditions was increased to 25 units.

One of the leading factors in the pathogenesis of disorders during the action of transversely directed g-forces is disorder of function of external respiration and circulation which leads to hypoxemia and hypoxia. This has stimulated a number of investigators to try in experiments on both animals and people the effectiveness of breathing under increased pressure during exposure to g-forces. V. I. Babushkin and E. V. Marukhanyan (1962) noted a significant increase in resistance, with respect to time (two-fold), if the subjects breathed pure oxygen or an atmosphere under excess pressure. This effect is explained by the authors as improving gas exchange in the lungs, and consequently, preventing the development of oxygen starvation.

The optimum magnitude of excess pressure at which the atmosphere must be supplied, according to the data of Watson and Cherniack (1962) is 2-3 mm Hg per G unit. During this process change in the indices of external respiration is to a significant extent prevented and the time of tolerance to g-forces was increased by 67%. True, chest pains did not noticeably decrease. In the

opinion of other authors (Longdon, Aeynolds, 1961; Hyde, 1961, and others), breathing pure oxygen with a simultaneous action of accelerations can cause unfavorable consequences similar to the clinical picture of oxygen poisoning.

Significant interest is posed theoretically and experimentally by a method of increasing tolerance to g-forces by the aid of immersion systems developed by K. E. Tsiolkovskiy. Morris et al. (1958), in experimenting on albino mice, noted that during immersion in water the mice tolerated accelerations up to 1,300 G for a period of 60 seconds. Similar data were obtained by a number of other authors. Wood et al. (1963) demonstrated that by immersing a man in water one could significantly increase his tolerance. During this process effectiveness was to a significant extent determined by the depth of immersion in water. Clarke and Grey (1961), in conducting investigations in a specially prepared container, achieved accelerations of 16 G with action in the head to seat direction when under ordinary conditions loss of peripheral vision with similar action of g-forces ensued at 3.25 G. It is important to note that /309 during this type of protection the subjects maintain freedom of movement of their extremities.

However notwithstanding the high effectiveness of this method its practical use in modern aircraft has proved impossible of accomplishment due to the great complexity and large dimensions of the immersion systems. All of this makes it necessary to refrain from seeking principles of developing protection against g-forces by the aid of hydrosystems and to seek out instead other methods of solving the complex problem.

In addition to seeking physical methods of protecting the organism against the effect of accelerations, its physiological reserves are also being sought. Many observations of aviation physicians have convincingly shown that overall hardening of the organism and special physical exercises directed toward improving mechanisms of regulating circulation and respiration, strengthening the muscles of the abdominal press and legs, and developing skills in transferring breathing from the abdominal type to the chest type and, on the other hand, the capacity for long term tonic stress of individual groups of muscles significantly increase tolerance of pilots to g-forces.

Increasing the resistance of the organism to accelerations is also achieved by means of conditioning in the centrifuge. The positive significance of familiarization-training rotations is not in doubt. However up to this time optimum conditions of conducting training rotations have not yet been developed and it is constantly necessary to bear in mind that in addition to training mechanisms of adaptation during exposures to high magnitude and long duration g-forces can produce morphological changes of a pathological character in the organism (V. G. Yeliseyev et al., 1963; Yu. N. Kopayev, 1969; Ye. F. Kotovskiy, 1963, and others).

It is known that one of the leading factors in the pathogenesis of disorders observed during a long term acting g-forces is the hypoxic or the circulatory form of oxygen starvation (P. K. Isakov, 1957; A. A. Sergeyev, 1957; V. I. Danileyko, 1962; Ye. A. Kovalenko, 1963; Gauer, 1961, and others). One can assume therefore that in conditioning the adaptive-compensating mechanisms to oxygen deficiency one can increase its resistance to the effect of g-forces. The justification of such an approach in experiments performed on animals was first confirmed by N. N. Sirotinin et al. (1962). The investigations specially conducted by us on several species of animals (N. N. Uglova, 1969), and with the participation of people (P. V. Vasil'yev, A. R. Kotovskaya, 1965) showed that adaptation to hypoxia under conditions of the pressure chamber and high altitudes is an extremely effective method of increasing the organism's resistance to g-forces.

Investigations are being conducted in the use of cooling with the goal of increasing the organism's resistance to the unfavorable conditions of space flights, including accelerations.

The first studies in studying the possibility of using pharmacological preparations for increasing tolerance to g-forces were conducted more than 20 years ago (Britton et al., 1946), however they did not receive the necessary development. This is due on the one hand to the fact that during flights in aircraft it is difficult to predict the exact time of onset of the effect of g-forces -- an important condition for the application of many pharmacological means, and on the other hand to the impossibility of using preparations which decrease the working capacity of the pilot (soporific, narcotic preparations, preparations of the phenothiazine series, etc.).

Most of these limitations are reduced when the subject is on flights aboard spacecraft.

In recent years a number of publications have appeared in which the results of both experimental investigations carried out on various species of animals and observations carried out on people in studying the effectiveness of vasoconstrictive preparations, vasodilators, ganglion blockers, narcotics, hormones, adrenomimetic means, central nervous system stimulators and a number of other substances are reported (I. I. Brekhman, 1961; V. Ya. Rusin, 1963; I. I. Pototskaya, 1964; L. V. Pastushenkov, 1967, 1968; Scane, Meineri, 1961, and others). The most favorable results, according to the data of experimental investigations are observed during the application of strychnine, the sympathomimetic amines, and certain of their prescription combinations (V. Ye. Belay et al., 1964, 1967). /310

In comparing known data on the pharmacological dynamics of preparations in the pathogenesis of the disorders which appear during accelerations it can be assumed that a favorable effect of most pharmacological substances is related to their effect on mechanisms of regulating circulation and respiration and on the supply of oxygen to vitally important organs and systems. The use of pharmacological means will be not only rational, but also extremely necessary during the descent of spacecraft following long term flights under conditions of weightlessness (P. V. Vasil'yev, A. R. Kotovskaya, 1965).

Naturally, the most promising will be combination uses of different anti-g-force means. Clarke and Grey (1961), in combining water immersion with a selected optimum pose, achieved in experiments carried out on people an increased resistance to 32.5 units. A. S. Barer et al. (1965), in using comparatively simple means (choice of optimal angle of inclination of chair back, profiled couch and breathing under increased pressure), observed increased tolerance of g-forces to 26.5 units. The cited data enabled one to hope that the development of this trend in investigations will lead in the future to even more effective results.

The materials presented in this section show that accelerations are among the factors which, on the one hand, are ever more frequently encountered in the life of modern man, and on the other hand, within certain parameters

(magnitude, rate of increment, and time of action) can cause severe disorders with respect to various systems of the organism. The basic pathogenic mechanism of the disorders which occur should be recognized as the hypoxic and circulatory form of oxygen starvation.

However there are yet many questions of the effect of g-forces on the organism which require answers. These primarily include making a study of the combined effect of accelerations with other flight factors (vibration, altered atmosphere, irradiation, etc.), the mechanisms of physiological reactions, and a search for means of protecting and treating in the case of development of disorders, etc.

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